

AD-A229 421



Development of a Ruggedized Hand-held Computer for Performance Testing in Operational Settings

By

John A. Caldwell, Jr.

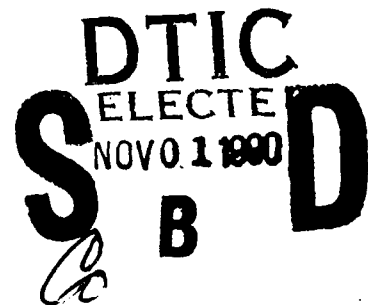
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and

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West Melbourne, Florida**

March 1990



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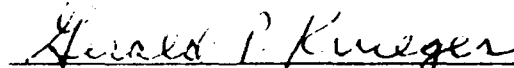
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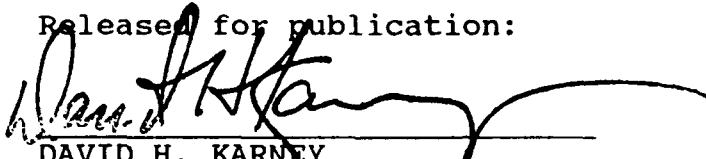
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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 90-8			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromed Resch Lab		6b. OFFICE SYMBOL (If applicable) SGRD-UAB-CS	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command		
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 577 Fort Rucker, AL 36362-5292			7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21701-5012		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code)			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO. 62787A	PROJECT NO. 3E162787 A879	TASK NO. BH
					WORK UNIT ACCESSION NO. 165
11. TITLE (Include Security Classification) Development of a ruggedized hand-held computer for performance testing in operational settings					
12. PERSONAL AUTHOR(S) Caldwell, J.A. Jr. and Young, C.					
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) 1990 March		15. PAGE COUNT 20
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Portable, ruggedized computers, field-hardened performance evaluation systems, hand-held data collection devices.		
12	06				
19. ABSTRACT (Continue on reverse if necessary and identify by block number) Portable, ruggedized computers, capable of administering standard automated tests under harsh environmental conditions, have been needed by researchers for many years. Particularly, military psychologists require tools which will permit the testing of soldiers during operationally-relevant field exercises without problems of equipment malfunctions. In 1984, the U.S. Army Research and Development Command sought to address this requirement by sponsoring a Small Business Innovative Research (SBIR) effort with Paravant Computer Systems, Inc. This SBIR resulted in the design and construction of the RHC-88, a notebook-sized, MS-DOS-based, IBM compatible computer which offers extensive programming flexibility in a portable, expandable, field-hardened unit. With the RHC-88, now it is possible to administer a wide variety of computer-based tests in the laboratory and in the field.					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION		
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)		22c. OFFICE SYMBOL

Foreword

Development of field portable psychological and physiological performance measurement systems is a core part of the applied research mission of the Biomedical Applications Research (BAR) Division at the U.S. Army Aeromedical Research Laboratory (USAARL). As a part of that program, the work reported here was conducted under a Small Business Innovative Research Program (SBIR) contract with Paravant Computer Systems, Inc., Contract No. DAMD17-85-C-5032 under sponsorship by the U.S. Army Medical Research and Development Command at Fort Detrick, Frederick, Maryland. Technical monitoring was accomplished by Mr. Ronald R. Simmons and Dr. John A. Caldwell of the U.S. Army Aeromedical Research Laboratory at Fort Rucker, Alabama. Mr. Craig Young, President of Paravant, was the principal researcher and engineer responsible for the conduct of the work and completion of the project.



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Introduction

As the U.S. Army is expected to operate efficiently under a wide variety of conditions, any problem that degrades soldier performance must be identified and corrected. Soldiers often are exposed to adverse weather conditions, prolonged work schedules, and inadequate sleep or rest. Sometimes soldiers are required to wear restrictive clothing (chemical protective gear) which poses physiological hazards from such factors as heat stress, and they may one day be required to complete their operational tasks under exposure to some pharmacological stressor (chemical antidotes for instance). All of these factors add to the sheer stress of battlefield conditions.

While the Army can't alleviate the stress produced by actual combat situations, it can develop a means for reducing the impact of many operational factors. However, establishment of countermeasures for any of the aforementioned problems requires a careful study of the precise nature of any degrading factor. In other words, it is possible for any stressor to degrade performance in a variety of ways, and the exact effect of any given stressor must be determined before a suitable correction or countermeasure can be proposed.

For instance, research on the effects of the chemical defense antidote atropine sulfate, administered in doctrinal doses, indicated soldier performance decrements will occur under the influence of the drug. Through the use of a variety of tests, it was determined that some causes of these decrements were simple visual input problems while others stemmed from varying combinations of changes in processing speed and accuracy. On several tests there was a general slowing of performance which lasted all day, but accuracy was often impaired only during the testing period closest to drug administration.

These results have a great deal of operational relevance because they suggest to commanders that soldiers are not completely incapacitated or dangerous to the point of being totally ineffective after atropine administration. However, they are compromised in some ways and at some points in time, and commanders must consider this information when assigning jobs to personnel if they expect to preserve unit efficiency and safety while the mission is being accomplished.

During times of military conflict, often there is no question about whether conduct of the mission must continue. Rather, the issue becomes how long it will take and how much it will cost in terms of equipment and personnel. Thus, in so far as the Army is able to predict the problems over which it may

exert control, and in so far as we are able to gain understanding over the exact impact of these problems, procedures can be developed which will maximize operational success in spite of known constraints.

For many years, the Department of Defense (DoD) has sponsored research designed to address these issues. Much of the work centers on major tactical and logistical concerns through large-scale field studies and training exercises designed to maximize the efficiency of troop deployment, equipment/supply distribution, personnel management, activity scheduling, and leadership. All of these factors are under constant evaluation, testing, and refinement so that our military effectiveness may be preserved. However, with the growing recognition of the importance of individual motivation, well being, and mental alertness, military strategists have begun to concern themselves with understanding and enhancing the status of individual soldiers. For this reason, the number of studies examining the effects of environmental, pharmacological, and work-related stressors on cognition, psychomotor skill, and motivation have increased.

To date, there have been numerous field studies on the effects of operationally relevant factors on soldier performance, and most of these are clearly related to understanding problems which will likely occur in a field environment. Before the advent of widespread computer technology, most assessments were done with paper and pencil tests, subjective field-test ratings of umpires, and specialist ratings and video filming. But in recent times, many of the direct assessments of performance have become microcomputer based. The prevailing level of computerization has had the benefits of greatly enhancing testing accuracy and standardization, efficient data storage and retrieval, and timely analysis. However, until recently much of this computerized testing has been limited to either a laboratory-simulation setting or an artificial type of field testing station because desktop and laptop computers are unable to withstand the temperature extremes, the dirt, the rain and mud, or the equipment abuse (e.g., vibration, bumps, and bounces) that tends to occur in field settings.

Both laboratory or field-test stations allow researchers to take advantage of the accuracy and simplicity afforded by new computer technology, while avoiding the most obvious pitfalls of field testing (hardware abuse). However, they frequently have the unwanted effect of reducing the degree to which research findings can be generalized to an actual operational environment. Clearly, there was need for a device

which could provide all of the positive aspects of computerized field testing without the limitations incurred by lack of ruggedization.

Objective

During fiscal year 1984, the U.S. Army Medical Research and Development Command (USAMRDC) sought to overcome the limiting factors of computerized field testing by preparing a solicitation to appear in the Defense Small Business Innovative Research Program (SBIR) catalog. The SBIR program encourages small businesses, possessing science and engineering capabilities to prepare innovative solutions to defense-related scientific problems, to submit proposals addressing issues relevant to various DOD components. Good proposals allow the company to receive research and development money.

The solicitation prepared by the Medical Research and Development Command was entitled "Miniature performance assessment battery," and it pointed out the problems with field study assessment of changes in soldier mood and cognition using currently available microcomputer technology. It also stated that there was a requirement for the construction of several small, portable testing devices which could be used with the presently available computer systems to conduct field research.

A small Florida-based company, Paravant Computer Systems, Inc., responded to the SBIR solicitation with a multifaceted proposal. Specifically, Paravant proposed to: 1) thoroughly analyze the existing performance assessment battery (PAB) developed by personnel at the Walter Reed Army Institute for Research (WRAIR) (Thorne et al., 1985); 2) document the existing system so it could be transported to a portable computer for use in the field; 3) work with personnel at the U.S. Army Aeromedical Research Laboratory (USAARL) to establish the exact requirements for a field operating computerized PAB; 4) study the available hand-held computers to determine applicability to a field PAB; 5) transport some or all of the existing (Apple-based) PAB software to a hand-held computer for trial evaluation; 6) work with USAARL personnel to determine the present and future requirements for a portable PAB system; and 7) propose the development of a PAB system which would meet or exceed the identified requirements.

Each of these components was fully addressed by Paravant in a proposal which demonstrated its ability to offer an innovative solution to an existing research problem. Paravant's response to the solicitation was favorably evaluated, which set Phase I in motion.

Phase I methodology

During the initial site visit for the Phase I effort, Paravant was familiarized with the Apple computer-based PAB obtained from WRAIR and in use at USAARL. A copy of the software was supplied to the Paravant principal investigator for review and evaluation so a thorough understanding of the system could be gained. Also, Paravant assessed the degree to which the currently available PAB (then operating on a standard Apple computer) met the needs of field research with regard to data handling and general user friendliness and workability. This evaluation revealed the current system could not permit a multiuser set up where multiple subjects could share the same computer; and it was not usable in an untethered field environment. Also, the systems did not allow easy tailoring of performance test batteries dependent upon subjects and/or research demands, nor did it permit a straightforward way to include new tests which might be required from time to time. Finally, the keyboard associated with the PAB needed improvement to make the testing environment more user friendly.

All of the above shortcomings of the Apple-based PAB were documented, and preparations were made to reprogram the system so it could be enhanced and subsequently transferred to a prototype field system. In addition, Paravant worked closely with USAARL personnel to ensure a solid understanding of what the future needs for a field testing system were so that any prototype system would include the desired newer features. All of this information formed the basis for Paravant's proposal for the development of a field portable cognitive assessment device.

Since the major requirement for a field testing device involved the ability to transport computerized tests away from the laboratory or similar settings, Paravant next surveyed the currently available portable computer systems. One criterion for selecting a system which would be suitable for field testing purposes was the capability to use the system without requiring the subject to be seated (or requiring him/her to find some place to set the testing device). Thus, an attempt was made to locate portable computers which were smaller than the standard lap-tops so tests could be taken while standing by holding the device in one hand while entering the answers to test items with the other hand. Other selection criteria focused on factors such as keyboard and display characteristics, networking capabilities, and ruggedization.

A search of existing portable computers showed no single device capable of meeting all of the requirements outlined. Therefore, it was decided an interim unit would be used for

software development and human factors testing. The interim unit would meet all of the requirements except ruggedization, and therefore could be used in limited field testing.

The interim unit selected was an Epson HX-40 "notebook" computer (Figure 1) because of its light weight, compact size, battery life, display, and ease of programming. In addition, the HX-40 was the only computer that provided a removable keyboard panel that allowed custom keyboard configurations to be installed. The custom keyboards proved very important during the human factors design of the portable PAB unit.

After selecting the computer, the PAB subtests that were part of the Apple-based system were implemented. This effort demonstrated the feasibility of developing a field-portable version of the PAB which was enhanced by the provision of using test-specific keyboard configurations. Also, this portion of the SBIR permitted in-depth problem evaluation, and the opportunity to identify needed system enhancements.

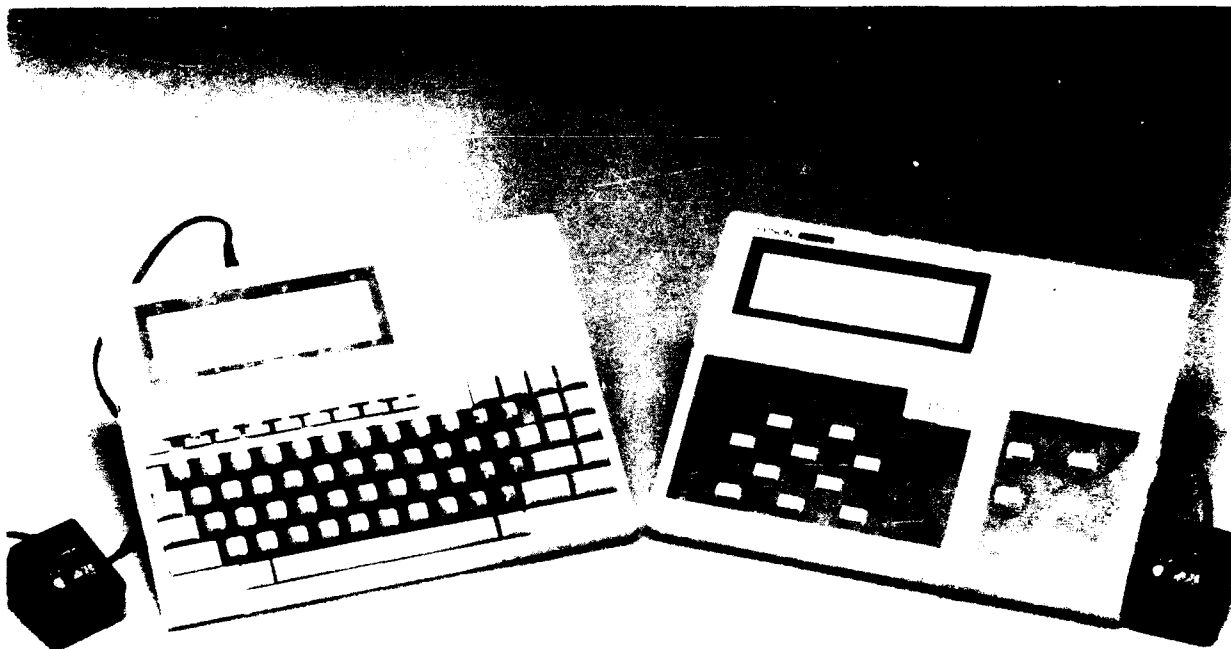


Figure 1. Epson HX-40 with QWERTY and PAB keyboard.

Phase I results

The feasibility demonstration with the Epson HX-40s showed a workable field portable testing system was attainable. The transfer of software from desktop to hand-held computer went smoothly despite hardware differences. Networking and individual monitoring capacities were demonstrated satisfactorily as well. However, many other desirable features for a comprehensive field testing system were deemed difficult or impossible to implement on currently available portable computer technology.

The need for testing subjects in day as well as night operations introduced a constraint that the PAB system should be workable in low lighting or in total darkness. The requirement for a wide variety of individual performance test batteries prompted Paravant also to suggest the implementation of custom keyboards tailored to specific testing demands. There was also an identified need for high density, nonvolatile data storage devices for gathering, removal, and transportation of collected data. The requirement for presentation of graphic displays suggested the need for high resolution screens. Furthermore, the need to provide physiological monitoring (and perhaps future psychophysiological assessments) in a field environment presented the requirement for analog-to-digital conversion at moderate to high sampling rates. Finally, Paravant noted the importance of implementing all of these capabilities on a computer which was hardened to a high degree of ruggedization because of the abuse often encountered by field equipment.

Based upon all these requirements and the absence of any available computer system to meet them, Paravant requested funding to define, specify, design, and develop a PAB computer system to meet the needs of Army research. In the interim, Paravant refined the Epson-based system so USAARL personnel could further study the demands and payoffs of cognitive testing in a field environment.

Phase II methodology

After reviewing the results of the Phase I effort and the results of field testing the HX-40, the next step was to "ruggedize" the HX-40 or find an equivalent machine to the HX-40 that was ruggedized already. Ruggedizing the HX-40 was quickly determined to be too costly an option and was eliminated. A search of rugged computers showed manufacturers were not headed in this direction due to the low demand for such machines. Therefore, Paravant proposed the development of a new hand-held computer which would exceed the

functional performance of the HX-40 and meet all of the ruggedization requirements. The system was not intended to be a portable version of existing desktop computers, but was designed to fulfill functions of field testing and a variety of commercial applications where full-screen, full-keyboard capabilities were not required.

The initial proposal

The proposal specified that Paravant would build a hand-held computer, smaller than a regular notebook, that weighed less than eight pounds. The structure of this computer would be of a highly rugged nature which would permit the continued use of the system under hostile environmental conditions. Thus, the computer would be able to function in poor weather or in the presence of high levels of dirt, dust, or mud. The case would allow the unit to withstand reasonable levels of shock and vibration. Peripheral interfaces would be arranged in a manner prohibiting incorrect connections. The display screen would be a liquid crystal display (LCD) approximately half the size of the entire computer.

The power requirements would be flexible enough to permit operation under a variety of circumstances. It was proposed the computer could be operated with a standard 115v AC adapter, or with either NiCad or alkaline batteries. The targeted battery life would allow 16 hours of continuous operation, and the internal memory system would be nonvolatile for at least 30 days from the time at which a low battery warning was displayed. Battery packs would be removable in the field environment without destroying the contents of memory while another pack was inserted.

The display requirements dictated a highly reflective LCD for use in direct sun with a backlight for use in low ambient light conditions. The display would have a minimum of 8 lines by 40 columns with pixel addressing for graphics use. The display would have to work over a wide temperature range with no significant degradation either temporary or permanent. The most important selection criteria for the display would be high contrast for ease of viewing.

The keyboard specifications required a very durable, rugged design with high-tactile response, interkey spacing that would allow use with chemical defense gloves and the capability to easily develop custom variations as dictated by human factors research. The custom variations included spacing, orientation, colors, and legends besides the number of keys.

The microprocessor selected would have to support a micro soft-disk operating system (MS-DOS) and emulate a standard desktop International Business Machine-personal computer (IBM-PC) as closely as possible. The processor would have to demonstrate a minimum level of processing speed to support the testing requirements.

The memory design of the new computer would have to meet several requirements. First, the memory architecture should emulate that of a desktop IBM-PC. Second, the memory must be of sufficient size to store the application program and the results of several days of testing. Third, and most important, the memory must remain intact even when the main batteries of the computer were completely discharged.

The computer would provide for a wide array of both internal and external interfaces. This would permit connection to analog-to-digital converters, telemetry systems, radios, modems, and external storage media. Also, the units would possess standard clock capabilities (date and time) as well as programmable interval timing with a resolution of 1 micro-second.

The operating system was proposed to be MS-DOS from MicroSoft Inc. since it was a well-proven operating system with all of the capabilities necessary for efficient computer operation. Also, the use of such a "standard" operating system would allow users to take advantage of a wide array of existing support tools for program development. Of course, this would mean users would not be required to return their computer to the factory every time a new application was specified since local programmers could handle the necessary programming changes.

Project structure

The actual development phase was split into several small scale tasks and a GANTT chart was specified for tracking purposes. This facilitated the logical progression from development to production. Some of the tasks were conducted concurrently with other tasks, while others required completion in a sequential fashion.

The first task was to write exact functional specifications for the field portable assessment system based on all of the requirements defined. This was accomplished by Paravant working very closely with designated USAARL personnel. After the functional specifications were determined, Paravant related the user and system functions to the applicable hardware and software structures. During this entire process,

such items as the functional capabilities, hardware/software capabilities, man-machine interface, hardware-software interface, performance requirements, and mechanical features of the system were delimited.

Once the functional specifications were written, the overall structure of the software system was designed to meet the detailed requirements. At this point, the operating system was specified as well as the precise nature of hardware/software interfaces and any support drivers necessary for the implementation of application software. Additionally, the structures of various application packages were defined.

Hardware architecture was likewise delimited based upon the requirements set forth in the functional specifications. The system processor was chosen and support processors needed for graphic and arithmetic functions were outlined as well. In October 1986, Paravant held a critical design review in which the overall design of the field portable performance assessment system was presented to USAARL personnel. At this time, all of the capabilities of the performance assessment system, as well as the total capabilities of the general system, were presented. Small changes were made to the system design, but basically, the system was approved clearing the way for development work to begin.

Prior to beginning the actual hardware design, three studies were undertaken to locate the best possible choice concerning 1) display technology, 2) battery technology, and 3) memory technology. These studies ensured a comprehensive survey of the available technology examined in view of USAARL requirements.

The type of desired display was one that was small, rugged, capable of both graphics and text display, readable under any lighting conditions, and operable on low voltage. Several types of displays were considered for meeting these constraints. Light emitting diode displays were examined, but eliminated because of poor graphics resolution and high power consumption. Vacuum fluorescent displays offered a number of desirable features, but they also did not offer high graphics resolution, and they weren't easily readable in bright sunlight. Gas discharge, or plasma, displays were eliminated because of excessive power consumption. Liquid crystal displays ultimately were chosen because of their size, flexibility, resistance to environmental damage, and especially their extremely low power consumption. The problem of operating in low lighting conditions was solved by backlighting the LCD with an electroluminescent panel.

A variety of battery types was considered to find one which was low cost, standard size, lightweight, and high energy. The computer design required battery voltage between 5.5 and 7.5 volts at a current draw of between 100 microamps (unit off) to about 400 milliamps (unit running full speed with display panel backlight on). Also, the selected batteries were required to be operable under temperatures ranging from -20 to +65 degrees Centigrade. Battery life was targeted to range from about 12 to 20 hours. Both nonrechargeable and rechargeable batteries were considered. In the nonrechargeable category, manganese alkaline (standard batteries), carbon zinc, and polycarbonmonofloride lithium batteries were examined. Ultimately, the manganese alkaline batteries were chosen because of low cost, wide availability, long life, and adequate operating temperature range. In the rechargeable category, both lead-acid and nickel-cadmium batteries were considered, but the nickel-cadmium batteries finally were selected. These batteries provide reasonable energy density, are easy to obtain, are low cost, and operate over a wide temperature range.

An evaluation of current and future memory technology was conducted. Given the requirements detailed earlier, both static complementary metal oxide semiconduction (CMOS) random access memory (RAM), and dynamic random access memory (DRAM) technologies were selected. DRAM was chosen for the 512K program execution memory because of its low cost and small package size. This memory consumed more power than the SRAM but because the duty cycle of the machine showed storage time (unit not executing a program) was much greater than operational time, the overall power consumption was not significant.

The SRAM memory was selected due to its very low power consumption. Because SRAM would be used for both 512K data storage and 1024K data storage, the lower power consumption more than offset the higher price and physically larger packaging size over the DRAM. Paravant pointed out dynamic memory is dense and relatively inexpensive, but it requires some overhead for proper operation. Static memory is much more expensive and requires more board space, but it's easier to interface with other internal components. Of the available devices, complementary metal oxide semiconductor (CMOS) fabrications were most desirable because of extremely low power consumption. As for packaging, both static and dynamic memory devices came in a variety of packages, but the J-leaded surface mount technology was most attractive for internal placement because of small space requirements. For the external, nonvolatile memory type, erasable programmable read-only memory (EPROM) chips were chosen.

The results of these three technology surveys and the effects of Paravant's findings on the proposed characteristics of the performance assessment system were presented to USAARL for informational and feedback purposes prior to the initiation of the final design stage. This meeting was held in January 1987, after which the design and prototype phase was initiated.

After this intermediate design review, the detailed design of the central processing unit (CPU), radio frequency (RF) board, power supply, and mechanical packaging was undertaken, breadboarded, laid out, tested, prototyped, and documented. Paravant began the CPU design task while taking into account the identified requirements of functionality, overall hardware architecture, power system, memory technology, screen (display) type, and operating system. The power supply design task took advantage of all of the knowledge gained from the first prototype system as well as the results of the technology reviews mentioned. Finally, the mechanical packaging was subcontracted to a company with experience in both mechanical design and packaging so that an enclosure with the necessary durability, reliability, and cost could be constructed.

Concurrently with all of the hardware development, the software design and development took place. First, the operating system (MS-DOS 3.2) was purchased. This particular operating system was chosen because: 1) it was felt that a commercially available system would offer much more flexibility than a custom-designed operating system, and 2) there was a fairly large amount of commercially available software which would run under this operating system. For instance, a user of the field portable assessment system would not be required to contract with Paravant or other specialized personnel each time a new application was considered since MS-DOS is familiar to most programmers and since a variety of programming (development) tools already are available for use under MS-DOS.

The selection of the operating system and definition of both the hardware and software environment permitted the completion of high level design for 1) the screen handlers, 2) the data transfer routines, 3) the analog-to-digital handlers, 4) the storage device handlers, and 5) the various components of the performance assessment system (test, report, analysis, data mover, and network interface). Also, the low-level, general use handlers (like print, copy, format, and directory commands) were designed as basic input output system (BIOS) routines on the EPROMs mentioned earlier. Finally, the complete performance assessment system was designed to be the first piece of application software. After a review of each of these design components was held, the routines were all coded and then tested to ensure proper operation.

Following the designing, coding, testing, and documenting of all the software, a final design review was held to present and demonstrate the preintegration software to USAARL. The documentation, which included a software reference manual, a users guide, and a performance assessment battery (PAB) guide, also was presented for review. Prior to this software review, an engineering prototype of the testing unit was constructed, debugged, and presented to USAARL for comments and/or suggestions.

Upon conclusion of the final software review, the telemetry unit was designed and developed. This part permitted the field portable assessment units to handle point-to-point data telemetry in an untethered mode. This development step included the design and layout of a telemetry printed circuit board. Also, in similar fashion, an analog-to-digital interface was planned and a prototype made. Upon completion of these two tasks, the final physical packaging of the unit was designed to incorporate any identified changes and three final cases were built.

All of the various hardware and software components were assembled, integrated, and tested as part of a unified system. At the completion of this testing (of preproduction units), the final integration was accomplished. This effort included the correction of any identified system anomalies, revision of printed materials, and a customer acceptance test. Most of the actual acceptance test took place in January 1988, but some of it was completed as late as April 1988. After this final acceptance test had taken place, the project was considered complete.

Phase II results

After approximately 2 years of effort, Paravant delivered two fully functioning RHC-88, hand-held, ruggedized, field-portable computerized assessment systems. Since then, Paravant has marketed the RHC-88 for a wide variety of applications, military and civilian field testing. The units have received a great deal of attention and have been well accepted.

The units are ruggedized to MIL-STD-810D to include the ability to survive a 4-foot drop, and to operate during immersion in 1 meter of water, under temperature extremes from -27 degrees to 145 degrees Fahrenheit, and during heavy vibration such as the type found in helicopters or field vehicles. There is room for two internal expansion boards for additional memory, internal modems, and parallel data ports. The RHC-88 offers full database interface which permits the

attachment of printers and other peripheral devices (Figure 2). The input/output capabilities include a built-in serial communications port conforming to EIA RS-232-D, and high speed optical ports capable of baud rates up to 19,200.

RHC-88 power is derived from either 5-pack rechargeable NiCads, alkaline C-cells, or an external wall transformer (Figure 3). The external connector for RS-232 is a bayonet connector which prevents moisture penetration into the case (Figure 4). The physical dimensions are approximately 9.5 x 6.3 x 2.5 inches (about the size of a textbook), and each unit weighs under 5 pounds. The keyboard is a standard tactile feedback, color-coded, alpha numeric type designed for gloved-hand use (Figure 5).

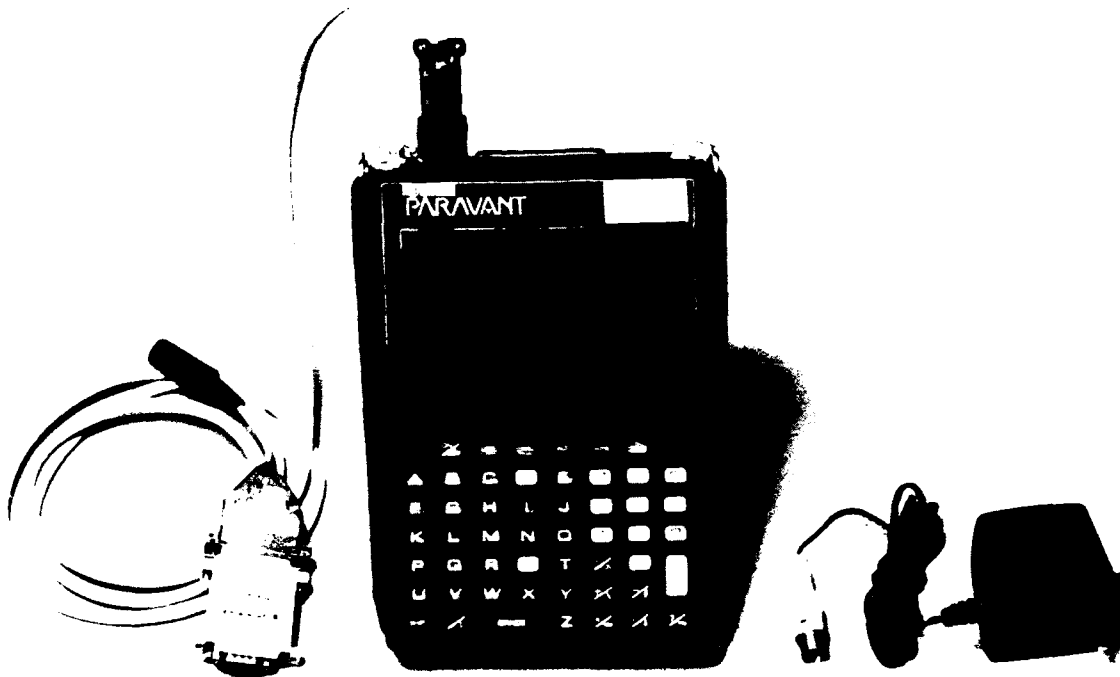


Figure 2. RHC-88 with interface cable and charger.

Each unit is equipped with a minimum of 512K RAM main memory expandable to 2.5 Mb. The memory is continuously powered by batteries for nonvolatile storage. The MS-DOS resides on 128K of ROM on the motherboard. Additionally, 64K of user accessible EPROM, for application programs, is expandable to 192K.

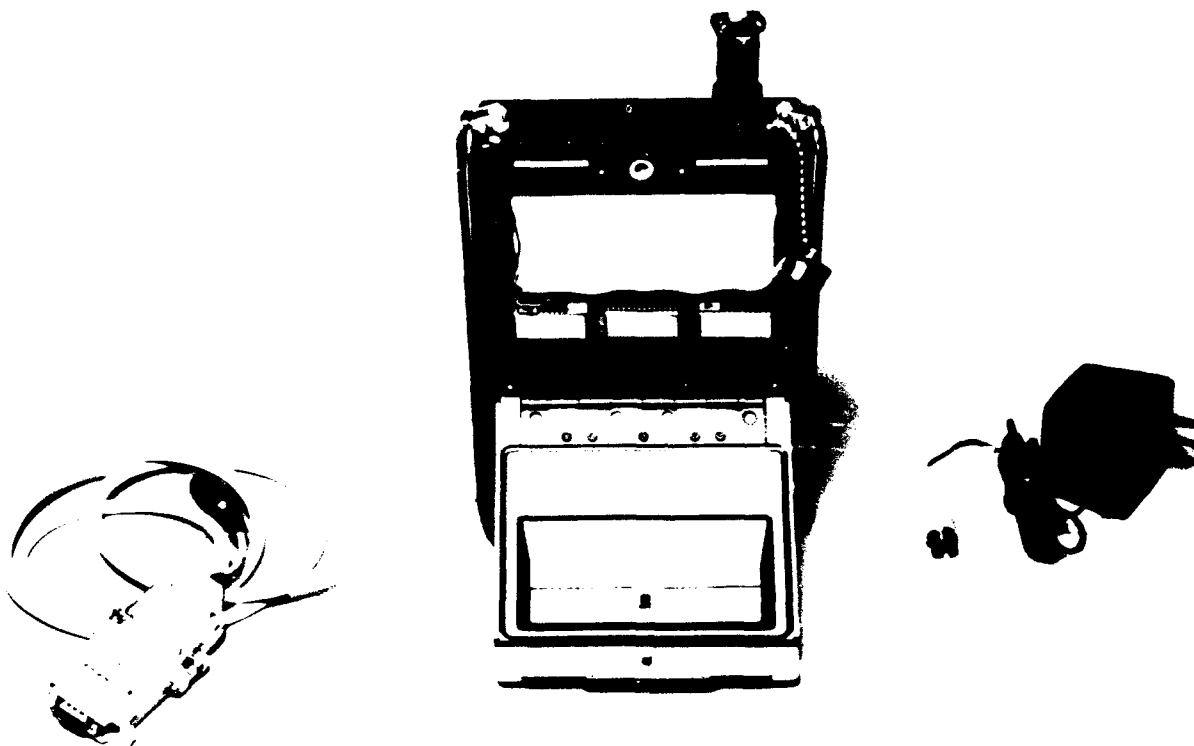


Figure 3. Battery compartment with NiCad battery pack.

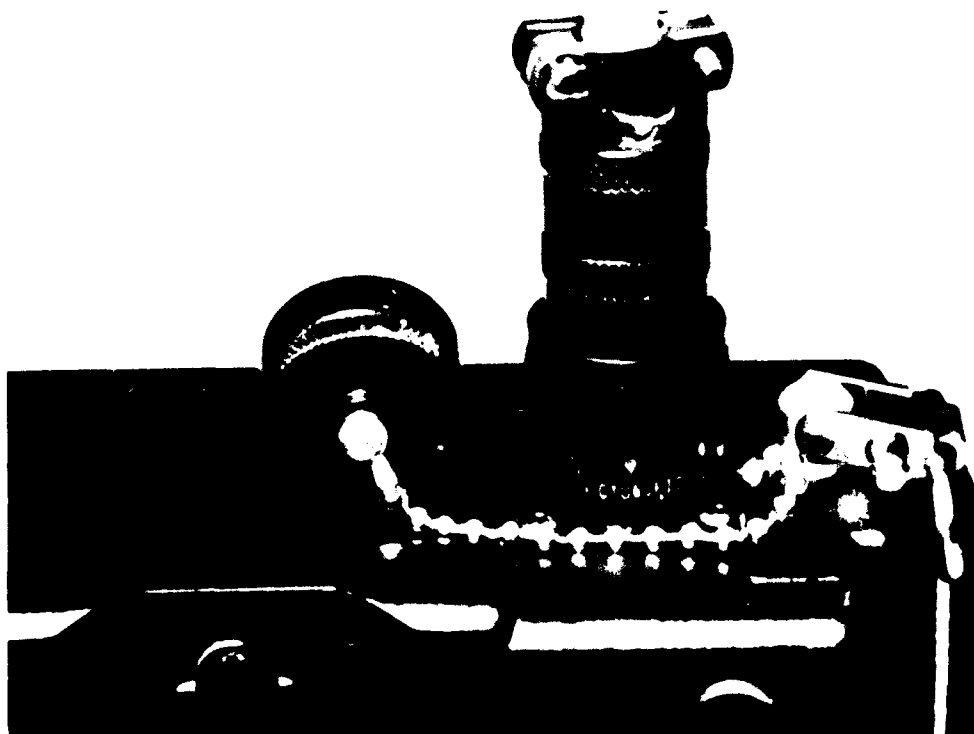


Figure 4. RS-232 bayonet connector.



Figure 5. Color-coded, tactile feedback keyboard.

The display is a high-contrast, super-twist liquid crystal display, 5 inches by 2.75 inches. This display offers 256 x 128 pixels of resolution for graphics and 16 lines by 42 characters for text. The individual character dimensions are .13 x .09 inches. The display is backlit for use in low lighting conditions or total darkness.

Supplied software consists of MS-DOS and file transfer programs for uploading and downloading text files, programs, and data to/from a personal computer (Figure 6). The software environment supports development in high-level languages such as ADA, C, Pascal, FORTRAN, and BASIC. Also, for field testing purposes, a version of the Walter Reed Performance Assessment Battery is available which includes subtests on letter searching (MAST-2 and MAST-6), encoding and decoding, two-column addition, serial addition/subtraction, logical reasoning, digit recall, two pattern recognition tasks, two mood/activation scales, and a 4-choice serial reaction time test.



Figure 6. RHC-88 configured for data download to a PC.

Units are delivered complete with manuals, cables, and an AC charger. There is an optional charger stand which holds the computer in an upright position, enables communication to external devices via optical interface (requiring no cable connections from the RHC-88), and provides both unit power and battery charging so the unit can be operated while charging. Optional expansion boards allow tailoring computer capabilities to meet changing operational demands.

Summary and conclusions

The RHC-88 computer designed and developed by Paravant Computer Systems clearly fills a vital need for both Army field research and industrial applications. The ruggedization, battery operation, nonvolatile memory, and expandability offered by these hand-held computers opens the door to applications which generally have precluded the use of a standard desktop PC. One of the most notable features of the RHC-88 is the advantages in terms of operational flexibility have not been offset by problems in the area of user interface. The use of MS-DOS as the operating system and the RHC's

adaptability to standard software development tools, make this computer as easy to use as the familiar IBM PC. Preliminary studies by USAARL personnel indicate the computers and available software are fully operational. Field studies already are being successfully conducted with these devices.

In summary, this Small Business Innovative Research effort has been a clear and compelling success. There already appears to be considerable payoff to both DoD and commercial markets.

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